VPE2504
3A, 40V, 2MHz Synchronous Step-Down Converter

Description

The VPE2504 is frequency adjustable, 3A, step-down converter with an integrated high-side and low-side switch. The current mode control is adopted in VPE2504 for fast loop response and easy compensation.

The VPE2504 operates with the wide input voltage from 4.5V to 40V and provides an adjustable output voltage from 0.805V to 30V. The VPE2504 features a PWM mode operation with up to 2MHz adjustable switching frequency.

Cycle-by-cycle current limiting, output over-voltage protection and thermal shutdown are provided for fault condition protections. An internal 2ms soft-start design reduces input start-up current and prevents the output voltage and inductor current to overshooting during power-up.

The VPE2504 is available in E-SOP-8L with thermally enhanced package.

Key Features

- 4.5V to 40V Input Voltage Range
- 3A Continuous Output Current
- 100mΩ/75 mΩ Internal Power MOSFET Switch
- Output Adjustable from 0.805V
- Up to 2MHz Adjustable Switching Frequency
- Cycle-by-Cycle Current Limit, Input Under-Voltage Lockout, Output Over-Voltage Protection and Thermal Shutdown
- Stable with Low ESR Output MLCC Capacitors
- 2ms Internal Soft-Start
- Thermally Enhanced E-SOP-8L Package

Applications

- 12V and 24V Distributed Power Systems
- Battery Powered Systems
- Industrial Power Systems
- LCD and Plasma TVs
- Automotive Systems

Typical Application

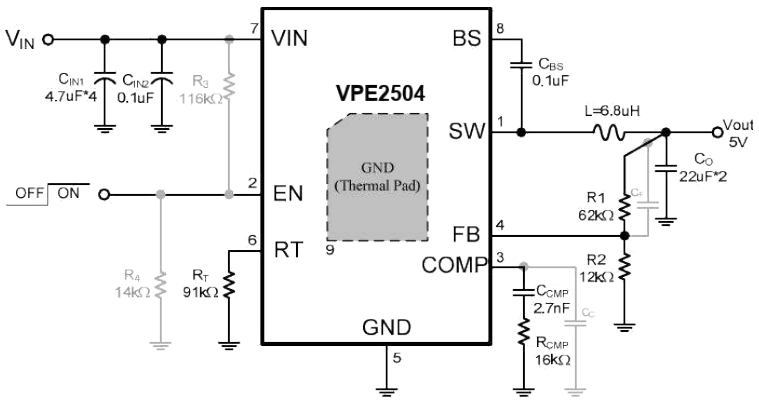
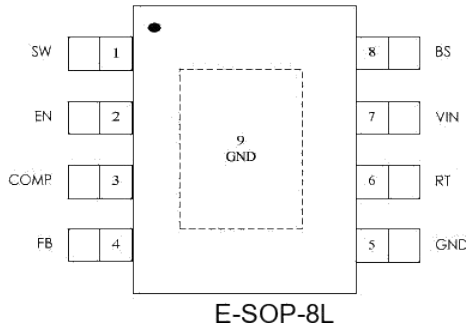


Figure. 1 VPE2504 application circuit

Package Configuration



E-SOP-8L

VPE2504-00SG08NRR

00 Adjustable Output

SG08 E-SOP-8L Package

NRR RoHS & Halogen free package

Commercial Grade Temperature

Rating: -40 to 85℃

Package in Tape & Reel

Order, Mark & Packing information

Package	Vout(V)	Product ID	Marking Code	Packing
E-SOP-8L	Adjustable	VPE2504-00SG08NRR	2504	Tape & Reel 3K units

Pin Functions

Name	E-SOP-8L	Function
SW	1	**Switch Node.** Must be connected to inductor. This pin connects to the internal main and synchronous power MOSFET switches.
EN	2	**Enable Pin.** On/Off control Input.
COMP	3	**Compensation.** This node is the output of Error Amplifier. Control loop frequency compensation is applied to this pin.
FB	4	**Feedback Pin.** This pin can be connected a resistor divider to set the output voltage range.
GND	5	**Ground Pin.** Connect exposed pad to GND plane for optimal thermal performance.
RT	6	**Frequency setting pin.** This pin can be connected to a resistor to GND to set the oscillator frequency.
VIN	7	**Supply Voltage.** The VPE2504 operates from a 4.5V to 40V.
BS	8	**Bootstrap.** This is the positive power supply for the internal floating high-side MOSFET driver. Connect a bypass capacitor (0.1uF) between BS and SW pin.
Thermal Pad	9	**Thermal Pad.** This pin must be connected to ground. The thermal pad with large thermal land area on the PCB will be helpful for chip power dissipation.

Functional Block Diagram

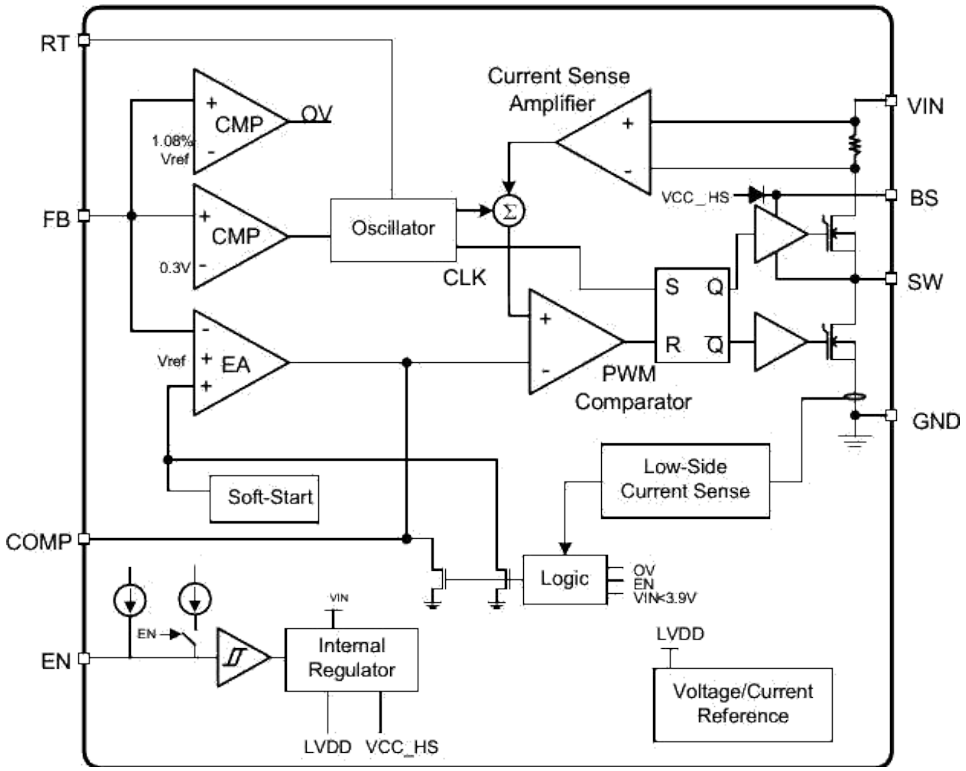


Fig. 2 Functional Block Diagram

Absolute Maximum Ratings

Devices are subjected to fail if they stay above absolute maximum ratings.

Input Voltage (V_{IN}) ..... –0.3V to +44V
Switch Voltage (SW) ..... –0.3V to V_{IN}+0.3V
Switch Voltage (SW, 10ns transient) .... –1.4V to V_{IN}+0.3V
Boost Voltage (BS) ..... V_{SW}–0.3V to V_{SW}+6V
Enable Voltage (EN) ..... –0.3V to V_{IN}
All Other Pins (RT, FB, COMP) ..... –0.3V to +6V
Lead Temperature (Soldering, 10 sec) ..... 260°C

Ambient Operating Temperature Range ... –40°C to 85°C
Junction Temperature (Notes 1) ..... –40°C to 150°C
Storage Temperature Range ..... –65°C to 150°C
ESD Susceptibility HBM 2KV
MM 200V

Recommended Operating Conditions

Input Voltage (V_{IN}) ..... +4.5V to +40V

Junction Operating Temperature ..... –40°C to 125°C

Thermal data

Package	Thermal Resistance	Parameter	Value
E-SOP-8L	θ_{JA} (Note 2)	Junction-ambient	50°C/W
	$\theta_{JC(top)}$ (Note 3)	Junction-case (top)	39°C/W
	$\theta_{JC(bottom)}$ (Note 4)	Junction-case (bottom)	2.4°C/W

Electrical Characteristics

V_{IN}=12V, T_A=+25°C, unless otherwise specified.

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Feedback Voltage	V_{FB}	4.5V≤V_{IN}≤40V	0.785	0.805	0.825	V
High-Side Switch on Resistance	$R_{ON(H)}$	-	-	100	-	mΩ
Low-Side Switch on Resistance	$R_{ON(L)}$	-	-	75	-	mΩ
Switch Leakage	I_{SW}	V_{EN}=0V, V_{SW}=0V or 12V	-	-	10	μA
High-Side Switch Current Limit	I_{LIMH}	-	-	5	-	A
Low-Side Switch Current Limit	I_{LIML}	From Drain to Source	-	1.8	-	A
COMP to Current Sensing Transconductance	G_{CS}	(Note 5)	-	4.2	-	A/V
Error Amplifier Voltage Gain	A_{EA}	(Note 5)	-	800	-	V/V
Error Amplifier Transconductance	G_{EA}	I_{COMP}=±10μA (Note 5)	-	1	-	mA/V
Error Amplifier Source Current	-	FB=0.6V	-	0.11	-	mA
Error Amplifier Sink Current	-	FB=1V	-	-0.11	-	mA
V_{IN} UVLO Threshold	V_{UVLO}	-	3.9	4.2	4.5	V
V_{IN} UVLO Hysteresis	-	-	-	300	-	mV
V_{OUT} Over Voltage Protection (OVP)	V_{OVP}	Percentage of V_{FB}	-	108	-	%
V_{OUT} OVP Hysteresis	-	Percentage of V_{FB}	-	104	-	%
Oscillation Frequency	F_{OSC}	V_{FB}=0.6V; R_T=100k	-	480	-	kHz
Shutdown Supply Current	-	V_{EN}=0	-	8	15	μA
Quiescent Supply Current	-	V_{EN}=2V, V_{FB}=1V	-	0.8	1.2	mA
Thermal Shutdown	T_{SD}	-	-	160	-	°C
Thermal Shutdown Hysteresis	-	-	-	30	-	°C
Minimum Off Time	T_{OFF}	(Note 5)	-	150	-	ns
Minimum On Time	T_{ON}	(Note 5)	-	150	-	ns
EN Input Low Voltage	-	-	-	-	0.4	V
EN Input High Voltage	-	-	1.5	-	-	V
EN Bias Current	I_{EN}	V_{EN}=2V	-	5	15	μA
EN Bias Current	-	V_{EN}=0V	-	1	3	μA

- **Note 1:** T_J is a function of the ambient temperature T_A and power dissipation P_D ($T_J = T_A + (P_D * \theta_{JA})$).
- **Note 2:** θ_{JA} is simulated in the natural convection at T_A=25°C on a highly effective thermal conductivity (thermal land area completed with >3*3cm² area) board (2 layers, 2S0P) according to the JEDEC 51-7 thermal measurement standard.
- **Note 3:** $\theta_{JC(top)}$ represents the heat resistance between the chip junction and the top surface of package.
- **Note 4:** $\theta_{JC(bottom)}$ represents the heat resistance between the chip junction and the center of the exposed pad on the underside of the package.
- **Note 5:** Guaranteed by design.

Typical Performance Characteristics

V_{IN}=12V, V_{OUT}=5.0V, T_A=25°C, unless otherwise specified.

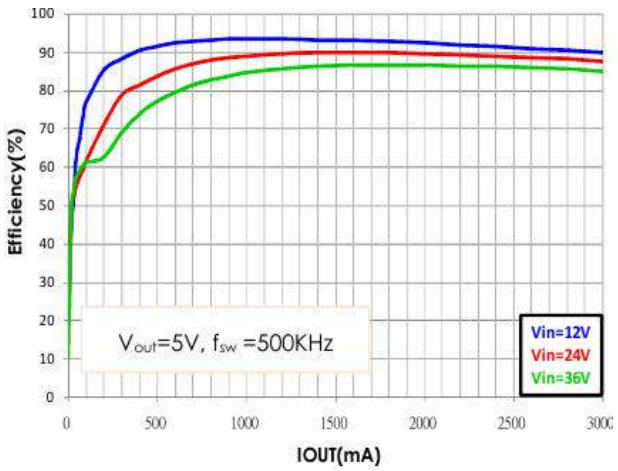


Figure 3. Efficiency vs. Load Current

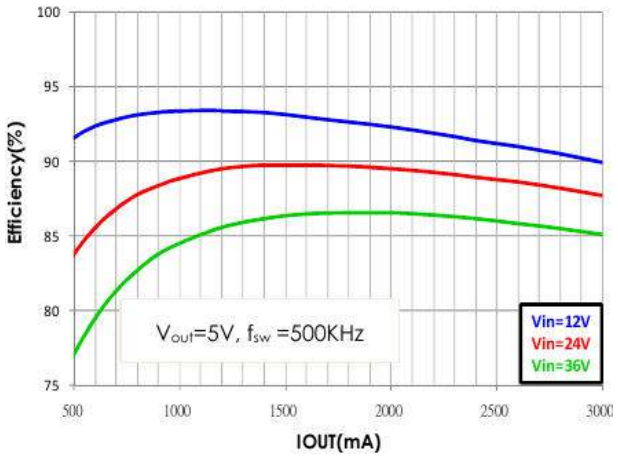


Figure 4. Efficiency vs. Load Current

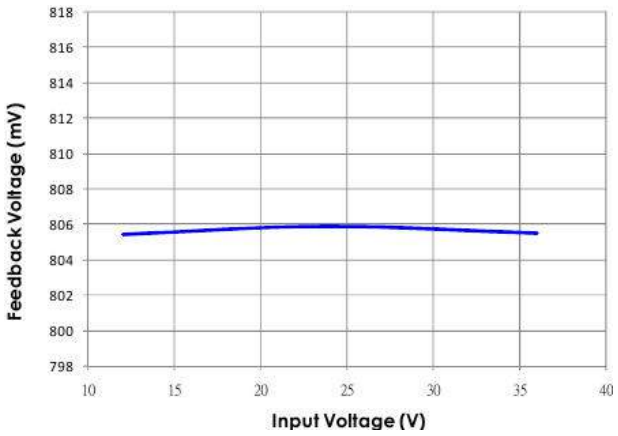


Figure 5. Feedback Voltage vs. Input Voltage

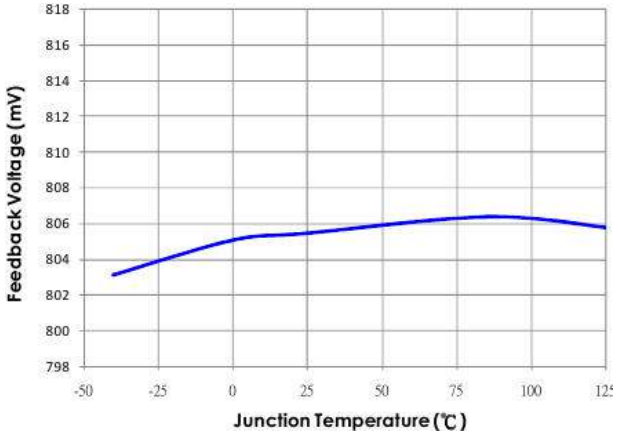


Figure 6. Feedback Voltage vs. Temperature

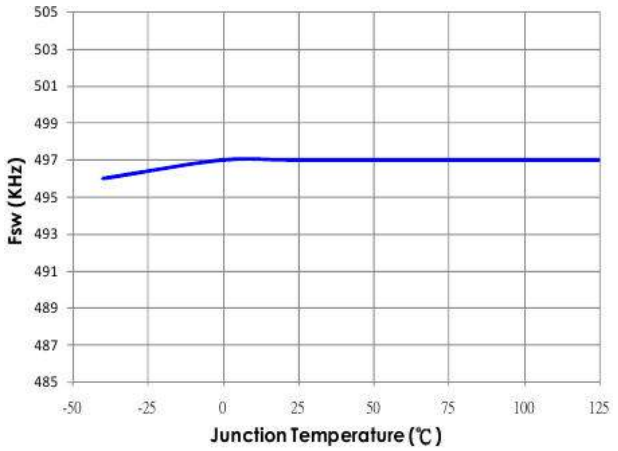


Figure 7. Oscillator Frequency vs. Temperature

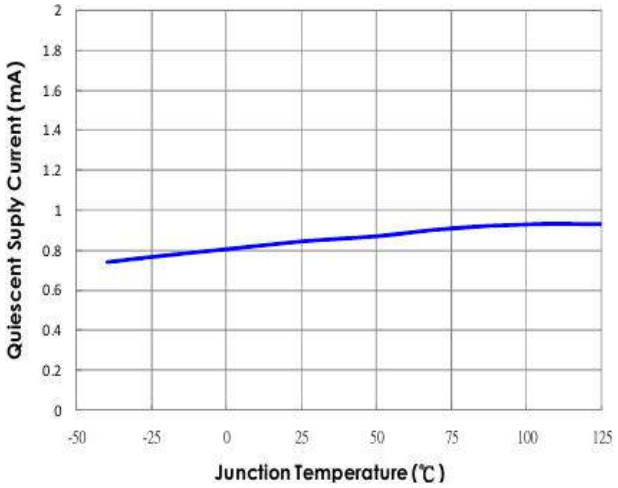


Figure 8. Quiescent Supply Current vs. Temperature

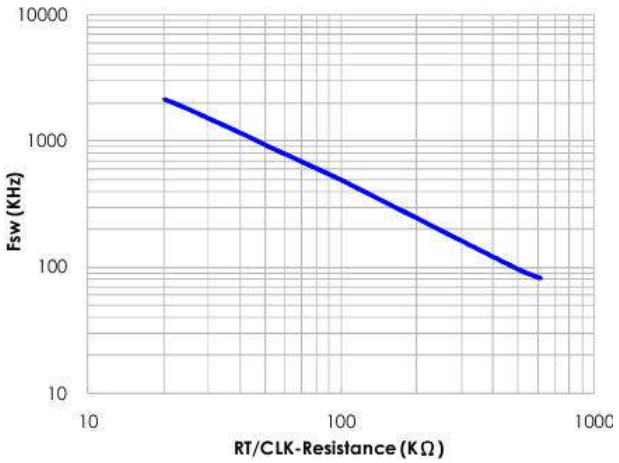


Figure 9. Oscillator Frequency vs. R_T Resistance

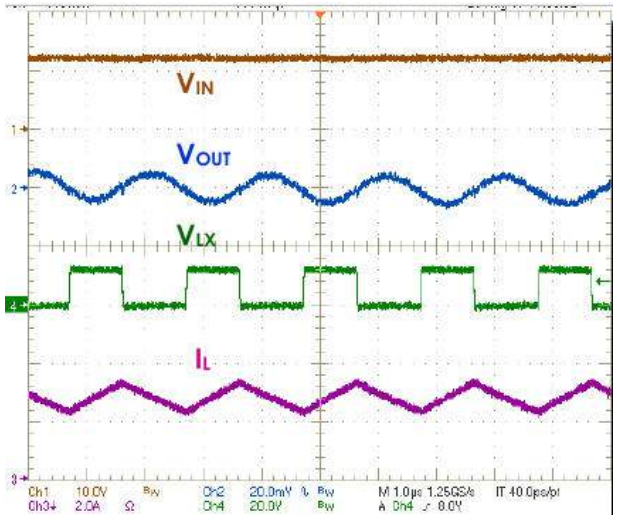


Figure 10. Operation Waveform

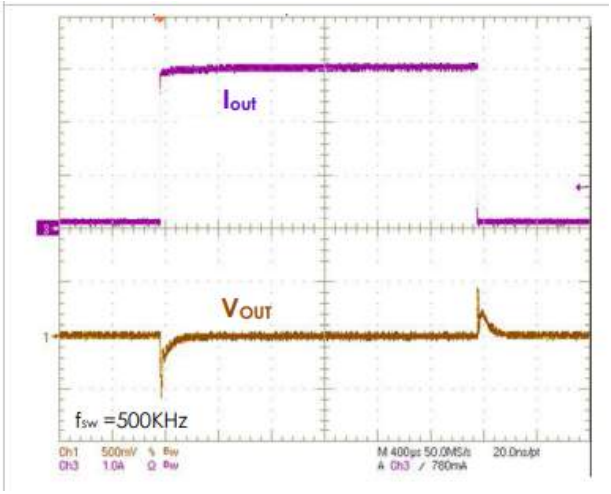


Figure 11. Load Transient Waveform (I_{OUT}=0.1A to 3A)

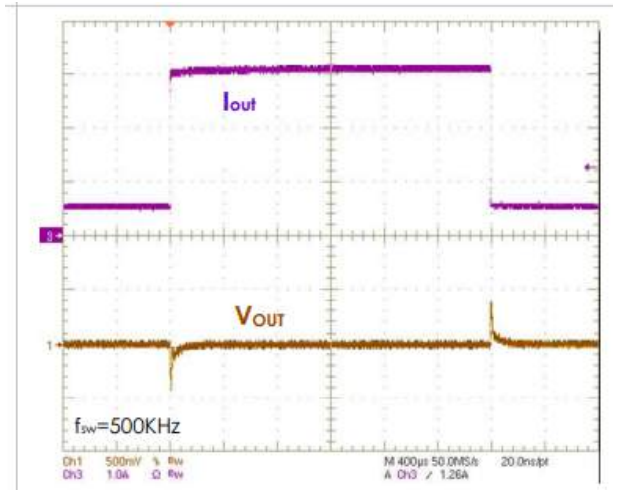


Figure 12. Load Transient Waveform (I_{OUT}=0.5A to 3A)

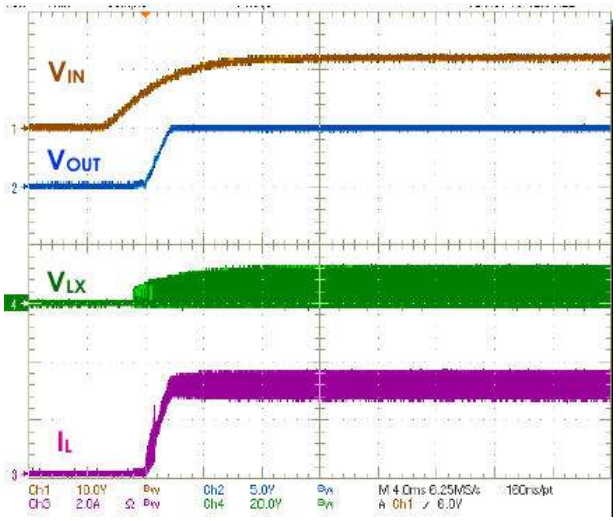


Figure 13. Power Up at Full Load Condition

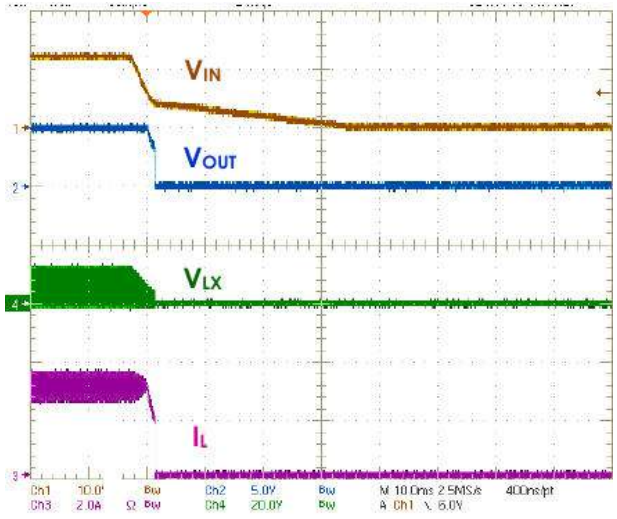


Figure 14. Power Off at Full Load Condition

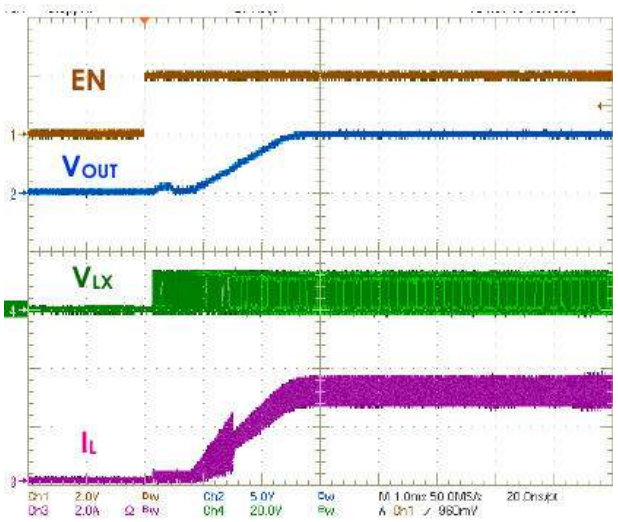


Figure 15. Enable Startup at Full Load Condition

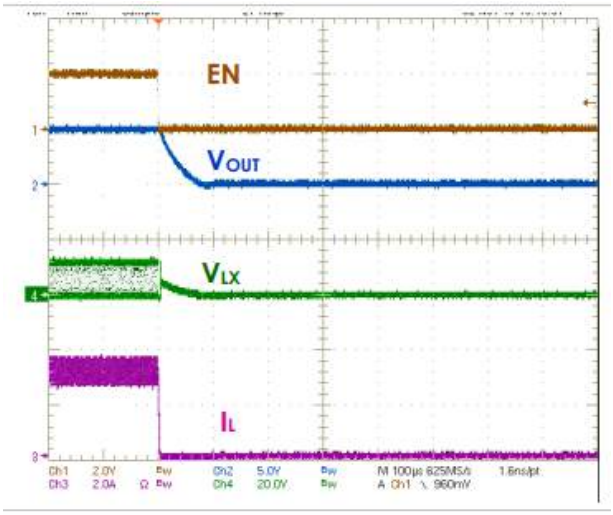


Figure 16. Enable Shutdown at Full Load Condition

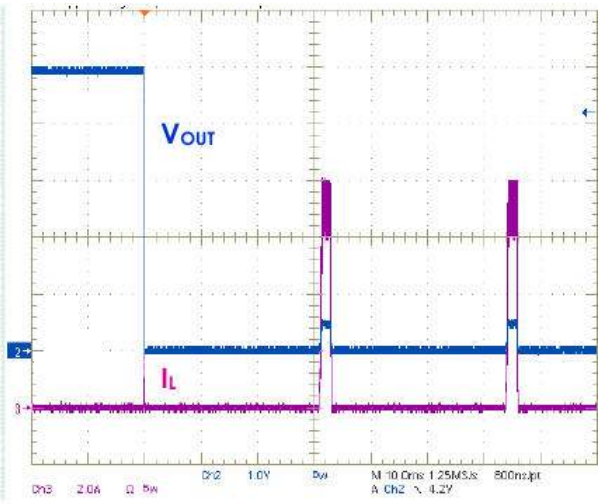


Figure 17. Short Circuit Waveform

Detailed Description

The VPE2504 is a variable frequency, current mode, automotive buck converter with an integrated high-side switch. The device operates with input voltages from 4.5V to 40V and tolerates input transients up to 44V.

Wide Input Voltage Range (4.5V to 40V)

The VPE2504 includes two separate supply inputs, VIN and BS, specified for a wide 4.5V to 40V input voltage range. VIN provides power to the device and BS provides power to the internal high-side switch driver. With respect to PWM minimum duty limit in VPE2504, the safe operating voltage area shall be considering in here.

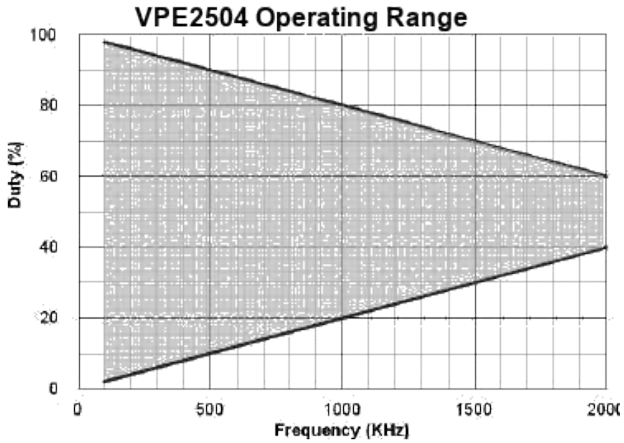


Fig. 3 VPE2504 Safe Operating Voltage Area

Error Amplifier

The error amplifier compares the FB pin voltage with the internal 0.805V reference and outputs a current proportional to the difference between the two. This output current is used to charge or discharge the external compensation network on COMP pin to form the COMP voltage used to control the power MOSFET current.

Minimum On-Time

The device features a 120ns minimum on-time to ensure the proper operation at high switching frequency and high differential voltage between the input and the output.

Enable Control

The VPE2504 has a dedicated enable control pin, EN. And that can be enabled or disabled by EN pulling high or low. For automatic start up, the pin EN would be tied to VIN through a 100kΩ resistor, and be pulled low for disable automatic start up function. When EN floating, the EN is pulled up to about 2.0V by an internal 1μA current source and the VPE2504 is enabled. In addition, the larger than 20μA current capability is needed for EN pulled down.

Over-Temperature Protection (OTP)

OTP limits the total power dissipation in the device. When the junction temperature exceeds 160°C, the internal thermal sensor will shuts down the whole chip, directly. Once the junction temperature drops below 130°C OTP is deactivated and VPE2504 turns to normal operation.

Output Over-Voltage Protection

Once the FB pin voltage of VPE2504 is over 0.87V ($\sim 1.08 * V_{FB}$), the high-side switch would be turned off and the low-side switch would be turned on, immediately. When inductor current is down to around zero current, the low-side switch would be turned off.

Input Under Voltage Lock-out (UVLO)

UVLO is implemented to protect the chip from operating at insufficient supply voltage. The UVLO rising threshold is about 4.2V while its falling threshold is about 3.9V. If a higher UVLO is required, designer can adjust the UVLO voltage via two external resistors and a filter capacitor. For example, the V_{start} and V_{stop} would be designed around 9V and 7V, and EN enable threshold is around 1.0V with 170mV hysteresis window for shutdown, the R_3=116k and R_4=14k are chosen.

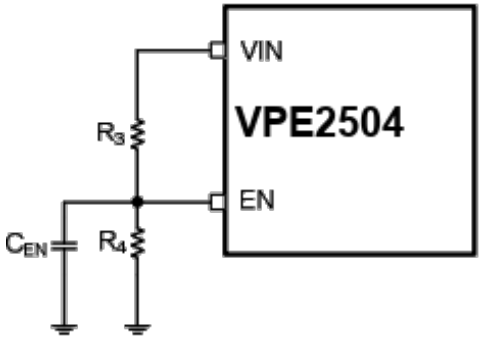


Fig. 4 Adjustable UVLO control circuit

Boost Capacitor

Connect a 0.1uF capacitor between the BS and SW. This capacitor provides the gate driver voltage for the high-side MOSFET. In addition, an UVLO in the floating supply is implemented to protect the high-side MOSFET and its driver from operating at insufficient supply voltage. The UVLO rising threshold is about 2.1V while its hysteresis is about 0.15V.

Over-Current Protection (OCP)

Over-current limitation is implemented by sensing the current across the high-side MOSFET. When the current exceeds the over-current threshold limit, the over current indicator is set true, and the over current limitation is triggered. Then, the high-side MOSFET is turned off for the rest of the cycle. The output voltage will start to drop if the output is dead-short to ground, suddenly. Once the FB is lower than 0.3V, the switching frequency is folded back to around 1/4 f_{SW}. However, when the over-current indicator is set true and the FB is lower than 0.3V, the short circuit protective function will be started.

Soft-Start

The typical soft-start time is designed about 2ms, and overshoot of the output voltage can be reduced by the function naturally.

Programmable Oscillator

The VPE2504 oscillating frequency is adjustable (200kHz~2MHz), that can be set by an external resistor R_T, which is connected from the RT to GND. And the value of R_T can be calculated as below equation:

$$\text{Frequency(kHz)} = \frac{3.75\,10^4}{R_T^{0.95}\ (\text{k}\Omega)}$$

Application Information

Previous section Fig.1 shows a typical application circuit of VPE2504. The IC can provide up to 3A maximum output current at the output voltage as 3.3V condition. For proper thermal performances, the exposed pad of the device must be soldered down to the PCB.

Setting the Output Voltage

Voltage on FB determines operating state on board, and the output voltage is set by the resistive voltage divider R_1 and R_2. Therefore, the output voltage can be calculated as below equation:

$$V_{FB} = V_{OUT} \frac{R_2}{R_1 + R_2},\ V_{OUT} = V_{FB} \frac{R_1 + R_2}{R_2}$$

Table1. Resistor Selection for Common Output Voltages

V_{OUT}	R1 (kΩ)	R2 (kΩ)
1.8V	33.3 (1%)	27 (1%)
2.5V	50.5 (1%)	24 (1%)
3.3V	37.2 (1%)	12 (1%)
5.0V	62.5 (1%)	12 (1%)
12V	278 (1%)	20 (1%)

Selecting the Inductor

The common rule for determining the inductance is to use the peak-to-peak ripple current in the inductor between 20% and 40% of the DC maximum load current, the sufficiently high saturation current rating and a DCR as low as possible. Generally, in order to acquire the faster transient response, a smaller size, a lower inductance, and a lower DCR inductor is utilized for the switching power supplies designed.

Nevertheless, the lower inductance causes the higher ripple current, larger output ripple voltage, and more efficiency loss at heavy load condition. Beside, a larger inductance is recommended to improve electrical transfer efficiency at light load condition. In addition, the system desired inductance L and peak to peak ripple current of inductor I_{LP} can be calculated as:

$$L = \frac{V_{OUT}}{f_{SW}\,\Delta I_L}\left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

$$I_{LP} = I_{LOAD} + \frac{\Delta I_L}{2} = I_{LOAD} + \frac{V_{OUT}}{2\,L\,f_{SW}}\left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Which f_{SW} is the switching frequency; I_{LOAD} is the load current, and I_{LP} is the inductor peak current.

Table2. Inductor Selection Guide

Model	I_{SAT} (A)	DCR (mΩ)	Manufacture
PCM104T-100MS	8.5	27 (typ.)	CYNTEC

Selecting the Input Capacitor

The BUCK converter with discontinuous conduction input current, therefore a capacitor is required to supply the AC current for step-down converter to maintain the DC input voltage. To use lower ESR capacitor design for the best performance. The high frequency impedance of the capacitor should be lower than the input source impedance for bypassing the high frequency switching current locally. Ceramic capacitors with X5R or X7R dielectrics are recommended because they have low ESR and better temperature coefficients to prevent excessive voltage ripple at input. Therefore the relationship between the input ripple and the capacitance could be estimated by:

$$\Delta V_{IN} = \frac{I_{LOAD}}{f_{SW}\,C_{IN}}\frac{V_{OUT}}{V_{IN}}\left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Selecting the Output Capacitor

The output capacitor C_O is used to maintain the DC output voltage, to keep the lower output ripple, and to ensure regulation loop stability. The output voltage ripple can be estimated by below equation, and the lower ESR capacitors are preferred.

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_{SW} L} \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \left(R_{ESR} + \frac{1}{8 f_{SW} C_O}\right)$$

Which R_{ESR} is the equivalent series resistance (ESR) of the output capacitor.

In case of lower ESR capacitor adopted, the output ripple is mainly caused by the capacitance and the output voltage ripple can be estimated by:

$$\Delta V_{OUT} = \frac{V_{OUT}}{8 f_{SW}^2 L C_O} \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Beside, the ESR dominates the impedance at switching frequency. After simplification, the output voltage ripple also can approximate estimated by:

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_{SW} L} \left(1 - \frac{V_{OUT}}{V_{IN}}\right) R_{ESR}$$

The characteristics of the output capacitor also affect the loop stability of regulation system. Lower ESR MLCC ceramic capacitors with X5R or X7R dielectrics are recommended.

Compensation Components

The transient response and system stability of VPE2504 are controlled by the COMP, which is the output of the internal error amplifier. A series capacitor-resistor pair is set to control the characteristics of the control system. The voltage feedback loop DC gain A_{DC} is shown in below equation. Besides, a compensator with better DC gain can enhance the stability at low frequency range.

$$A_{DC} = \frac{R_L G_{CS} A_{EA} V_{FB}}{V_O}$$

Where R_L, G_{CS}, and A_{EA} are load resistor value, current sensing transconductance and error amplifier gain, respectively.

For closed loop response, a compensator is used to increase bandwidth, to improve high-frequency noise immunity, and to acquire better stability. Note that three components (R_{CMP}, C_{CMP}, and C_C) are involved in determining the poles and zero, and the locations of the poles (f_{p1}, f_{p2}, and f_{p3}) and zero (f_{z1}, and f_{ESR}) as following:

$$f_{p1} = \frac{1}{2\pi C_{CMP} r_O} = \frac{G_{EA}}{2\pi C_{CMP} A_{EA}}$$

$$f_{p2} = \frac{1}{2\pi C_O R_L}$$

$$f_{p3} = \frac{1}{2\pi C_C R_{CMP}}$$

$$f_{Z1} = \frac{1}{2\pi C_{CMP} R_{CMP}}$$

$$f_{ESR} = \frac{1}{2\pi C_O R_{ESR}}$$

Where, G_{EA}, r_O, R_L, C_O, and R_{ESR} are the error amplifier transconductance, output resistor of error amplifier, load resistor, output capacitor, and output capacitor ESR, respectively.

Therefore, the f_{P3} pole set by the compensation capacitor C_C which is directly connected COMP to GND, and the compensation resistor R_{CMP} is used to compensate the effect of the ESR zero f_{ESR} on the loop gain. To shape the converter transfer function for getting an adequate loop gain is the purpose of compensation design. The system open loop unity gain crossover frequency is important.

Besides, the lower crossover frequencies result in slower line and load transient responses, while higher crossover frequencies could cause the system unstable. A good compromise is to set the crossover frequency to below one-tenth of the switching frequency.

To optimize the compensation components, the following procedure can be used:

1. R_{CMP} is used to set the desired crossover frequency. Determine the R_{CMP} value by the following equation:

$$R_{CMP} = \frac{2\pi C_O f_C}{G_{EA} G_{CS}} \frac{V_O}{V_{FB}}$$

Where, f_C is the desired crossover frequency.

2. C_{CMP} is used to set the desired phase margin. For typical applications, f_{Z1} is set lower than one-fourth of the crossover frequency to provide sufficient phase margin. The C_{CMP} value can be calculated by the following equation. To avoid the output voltage unstable due to the parasitic capacitor between the COMP pin and GND, the C_{CMP}>100pF is strongly recommended.

$$C_{CMP} > \frac{4}{2\pi R_{CMP} f_C}$$

Where, R_{CMP} is the compensation resistor value.

3. Determinate C_C, if the ESR zero of the output capacitor is located at less than half of the switching frequency, the second compensation capacitor C_C is required, and which can be valid by the following relationship:

$$\frac{1}{2\pi C_O R_{ESR}} < \frac{f_{SW}}{2}$$

For above item 3 condition, please add the second compensation capacitor C_C to set the pole f_{P3} at the location of the ESR zero. Determine the C_C value in the following equation:

$$C_C > \frac{C_O R_{ESR}}{R_{CMP}}$$

Besides, a 3∼5pF capacitance is suggested to improve full range operating.

Table4. Components Selection Guide

V_{OUT} (V)	L (μH)	C_O (μF)	R_{CMP} (kΩ)	C_{CMP} (nF)
1.8	2.2	22*2	8.2	2.7
2.5	3.6∼6.8	22*2	10	2.7
3.3	4.7∼10	22*2	12	2.7
5.0	4.7∼10	22*2	16	2.7
12	10∼22	22*2	24	2.7

4. The estimation is based on 15% of Iout current for table4. User can calculate the values by depending on peak-to-peak ripple current real requirement.

External Bootstrap Diode

For V_{IN} is lower than 5V or duty ratio is higher than 65 percentage conditions, an external bootstrap diode is recommended to add between external 5V supplied voltage (or V_{OUT}) and BS to improve the efficiency of regulator. The low cost diode can be used for this application such as 1N4148.

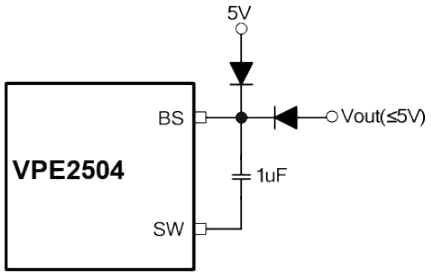
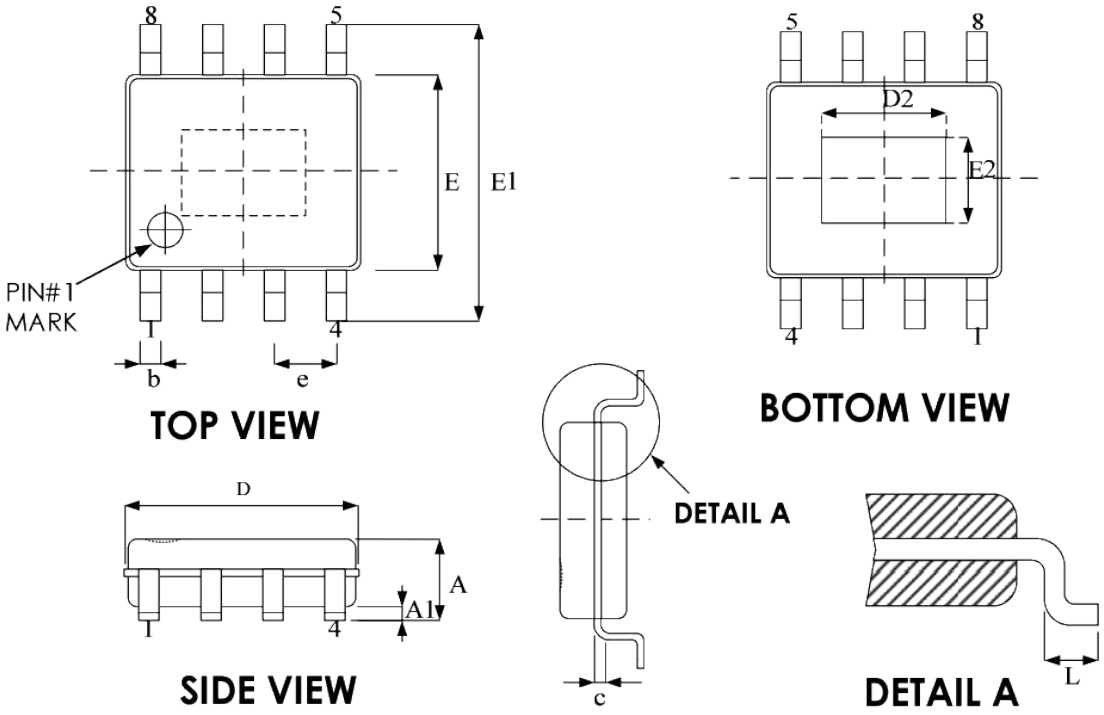


Fig.5 External Bootstrap Diode

Fig. 5 External Bootstrap Diode

Package Outline Drawing



E-SOP-8L

Symbol	Dimension in mm	
	Min.	Max.
A	-	1.70
A1	0.00	0.15
b	0.31	0.51
c	0.10	0.25
D	4.80	5.00
E	3.81	4.00
E1	5.79	6.20
e	1.27 BSC	
L	0.40	1.27

Exposed pad

Symbol	Dimension in mm	
	Min.	Max.
D2	2.80	3.50
E2	2.00	2.60

Disclaimer

The information provided in this datasheet is believed to be accurate and reliable. Errors or omissions are expected. indiaVP Semiconductor Pvt. Ltd. reserves the right to make changes to the product specifications without prior notice. Users should verify the suitability of the product for their specific applications. Please visit our website for the latest datasheet.

Contact Information

indiaVP Semiconductor Pvt. Ltd.

Email: sales@ivpsemi.com

Website: www.ivpsemi.com